Detailed List of Topics

What follows is a rather detailed list of topics we covered during the lectures. On the other hand, as any list of this kind, this is just a quick reference for your convenience but you should always check the lectures for any doubt (especially this year where they were all recorded).

You should be able to discuss and describe the formulas, updates and algorithms seen during the lectures. Some exercises and questions might involve also the understanding of the derivation and proof seen in class (this applies only to the derivation explained in class and not to the ones that have been covered only in the books). Finally, you should be able to understand snippets of Matlab code and to do exercises similar to the ones included in the notes of exercise sessions.

Introduction

- Overview of Machine Learning
- Learning Paradigms (Supervised, Unsupervised and Reinforcement Learning)

Supervised Learning

- Overview of Supervised Learning
- Elements of Supervised Learning (Representation, Evaluation, Optimization)
- Taxonomy of Supervised Learning

Linear Regression

- Problem Definition
- Linear models and basis functions
- Ordinary Least Squares
- Least Mean Square update
- Geometric interpretation of Ordinary Least Squares
- The overfitting problem
- Regularization: Ridge Regression and Lasso
- Maximum Likelihood and comparison with ordinary least squares
- Bayesian Linear Regression: overview, maximum a-posteriori, relationship with maximum likelihood and with regularization, predictive distribution

Classification

- Definition of Problems and Approaches (discriminant function, probabilistic discriminative, probabilistic generative)
- Generalized Linear Models
- Label Encoding
- Discriminant Function: 2-class and multi-class
- Linear Basis Function Models
- Least Squares for Classification
- Perceptron
- Logistic Regression: maximum likelihood for binary classification
- Multi-class Logistic Regression
- Logistic Regression vs Perceptron Algorithm

Model Evaluation, Selection and Ensembles

- Bias-Variance Decomposition
- Training Error vs Test Error
- Validation

- Cross-Validation: Leave-One-Out Cross Validation and K-Fold Cross Validation
- Complexity-Adjusted Model Evaluation
- No Free Lunch Theorems
- Curse of Dimensionality
- Feature Selection: Filter, Embedded and Wrapper (Backward and Forward Selection)
- Dimensionality Reduction: Principal Component Analysis
- Bagging
- Boosting: AdaBoost
- Comparison of Bagging and Boosting

Computational Learning Theory

- Overview and Definitions
- Version Space
- Bounds for Consistent Learners
- PAC-Learning
- Bounds for Agnostic Learners
- VC Dimension: definition and VC bounds

Kernel Methods

- Kernel: definition, meaning, and properties
- Kernel Trick
- Kernel Ridge Regression: Dual Representation, Gram Matrix, Prediction Function, Dual vs Original Representation
- Design of Kernels: Direct Method and Mercer Theorem
- Popular Kernels: Polynomial, Gaussian, Symbolic, Generative
- Kernel Regression: method and interpretation

Support Vector Machines

- Definition of Sparse Kernel Machines
- Maximum Margin Classifier
- Dual Problem
- Support Vectors
- Soft-Margin Classifier: Dual Representation
- nu-SVM
- Chunking
- Osuna's Method
- SMO
- Multi-Class SVM

Markov Decision Process

- Sequential Decision Making
- Agent-Environment Interface
- Finite Markov Decision Process
- Return in Episodic Tasks
- Return in Continuing Tasks (discount)
- The reward hypothesis
- Policy (deterministic/stochastic, markovian/not-markovian)
- Value Functions Definition
- Bellman Expectation Equations
- Optimal Policy in MDP
- Optimal Value Functions
- Bellman Optimality Equations

Dynamic Programming

- Iterative Policy Evaluation
- Policy Improvement Theorem
- Policy Iteration
- Generalized Policy Iteration
- Value Iteration
- Asynchronous DP and Efficiency

Monte Carlo Methods

- Sampling methods (pro and cons)
- First-Visit an Every-Visit Monte Carlo policy evaluation
- Monte Carlo for policy iteration
- Exploration
- Monte Carlo Policy Iteration with Exploring Starts
- epsilon-Greedy Exploration
- epsilon-soft Monte Carlo Policy Iteration
- epsilon-Greedy Policy Improvement Theorem
- On-Policy vs Off-Policy Learning (overview, target and behaviour policy)
- Importance Sampling
- Off-Policy Every-visit Policy Evaluation
- Off-Policy MC Control

Temporal-Difference Learning

- TD(0) update
- TD(0) Policy Evaluation
- MC vs TD (pro and cons, Bias-Variance, Sampling and Bootstrapping)
- SARSA
- Q-Learning
- Overview of Eligibility Traces

Multi-Armed Bandits

- Exploration-Exploitation Dilemma
- Stochastic MAB Setting
- UCB1
- Thompson Sampling
- Adversarial MAB Setting
- EXP3
- Other type of MABs